Port of Seattle

EAST WATERWAY OPERABLE UNIT

SUPPLEMENTAL REMEDIAL INVESTIGATION/ FEASIBILITY STUDY

TECHNICAL MEMORANDUM:

~~ANTHROPOGENIC BACKGROUND EVALUATION~~FINAL ANTHROPOGENIC BACKGROUND EVALUATION

For submittal to

The U.S. Environmental Protection Agency
Region 10
Seattle, WA

~~June~~July **2021**

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ABBREVIATIONS

μg/kg	micrograms per kilogram
AB	anthropogenic background
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
cm	centimeter
cm/yr	centimeters per year
COC	contaminant of concern
CSM	conceptual site model
CSO	combined sewer overflow
dw	dry weight
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
EW	East Waterway
EWG	East Waterway Group
FS	Feasibility Study
in/day	inches per day
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
mg/kg	milligrams per kilogram
ng/kg	nanograms per kilogram
PCB	polychlorinated biphenyl
Port	Port of Seattle
PRG	preliminary remediation goal
Q-Q	quantile-quantile
RAO	remedial action objectives
RBTC	risk-based threshold concentration
RI	remedial investigation
RM	river mile
RME	reasonable maximum exposure
ROD	Record of Decision
ROS	regression on order
SRI	Supplemental Remedial Investigation
TEQ	toxic equivalent
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Executive Summary

This memorandum develops site-specific anthropogenic background (AB) estimates for total polychlorinated biphenyls (PCBs), dioxins/furans, and arsenic for the East Waterway (EW) sediment Operable Unit of the Harbor Island Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Superfund site located in Seattle, Washington. This AB evaluation is part of the EW Supplemental Remedial Investigation and Feasibility Study process to support the U.S. Environmental Protection Agency's (EPA's) development of the Proposed Plan and Record of Decision for the EW sediment Operable Unit.

AB estimates were developed as part of a collaborative process between EPA and East Waterway Group (the Port of Seattle, City of Seattle, and King County), and in coordination with key stakeholders (the Muckleshoot Tribe and the Suquamish Tribe), in meetings held in 2020.

AB estimates were developed based on the EW conceptual site model regarding sediment inputs to the EW, which is predominantly from Green River suspended sediments (approximately 99 percent) and a very small amount from urban inputs (approximately 1 percent).[1] Available datasets representing solids inputs to the EW included upstream Green River suspended solids, surface water, and bedded sediment, as well as storm drain and combined sewer overflow solids in the urban drainage basins to the EW and the Lower Duwamish Waterway (upstream of the EW). Following screening of these datasets, Green River suspended solids data were deemed most acceptable and representative as the AB dataset. These data were further evaluated to support dataset refinement and adjustment, identify potential uncertainties, and develop AB estimates for the EW Superfund site. The selected AB values based on the 95 percent upper confidence level on the mean statistic are as follows:

- Total PCBs: 31 micrograms per kilogram (µg/kg) dry weight (dw)
- Arsenic: 20 milligrams per kilogram (mg/kg) dw
- Dioxins/furans:
  - 1,2,3,7,8-PeCDD (Pentachlorodibenzo-p-dioxin): 2.1 nanograms per kilogram (ng/kg) dw
  - 2,3,4,7,8-PeCDF (Pentachlorodibenzofuran): 1.1 ng/kg dw
  - 2,3,7,8-TCDD (Tetrachlorodibenzo-p-dioxin): 0.71 ng/kg dw
  - 2,3,7,8-TCDF (Tetrachlorodibenzofuran): 1.2 ng/kg dw

[1] Percentages based on the estimates for the future case scenario following source control; see EW Feasibility Study Section 5 (Anchor QEA and Windward 2019).

1 Introduction

This technical memorandum develops site-specific anthropogenic background concentration (AB) estimates for total polychlorinated biphenyls (PCBs), dioxins/furans, and arsenic for the East Waterway (EW) sediment Operable Unit of the Harbor Island Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Superfund site located in Seattle, Washington. Estimation of AB for these contaminants of concern is part of the EW Supplemental Remedial Investigation (SRI) and Feasibility Study (FS) process, and supports the U.S. Environmental Protection Agency's (EPA's) development of the Proposed Plan and Record of Decision (ROD) for the EW sediment Operable Unit. This work was performed under the October 2006 Administrative Settlement Agreement and Order on Consent with the Port of Seattle (Port) and EPA after EPA required this work as part of a supplement to the SRI/FS Work Plan for the Administrative Settlement Agreement and Order on Consent on December 16, 2020. The East Waterway AB values are site-specific for the EW site and are not appropriate for use at other sites.

1.1 Background

The EW is a 1.5-mile-long, 157-acre maintained commercial waterway along the east side of Harbor Island, immediately downstream of the Lower Duwamish Waterway (LDW) Superfund site, which extends for 5 miles upstream (Figure 1-1). In 2006, the Port entered into the Administrative Settlement Agreement and Order on Consent for development of a SRI/FS for the EW. The Port subsequently entered into a Memorandum of Agreement with the City of Seattle and King County to jointly conduct the SRI/FS as the East Waterway Group (EWG). The SRI was approved by EPA in 2014 (Windward and Anchor QEA 2014), and the FS was approved by EPA in 2019 (Anchor QEA and Windward 2019).

1.2 Problem Definition

The FS preliminary remediation goals (PRGs) were established based on natural background[2] for total PCBs, dioxins/furans, and arsenic, because risk-based threshold concentrations (RBTCs) for human health remedial action objectives (RAOs) for these chemicals were less than natural background concentrations. Natural background concentrations and associated RAOs established in the FS are as follows (FS Table 4-3):

- Total PCBs: 2 micrograms per kilogram (µg/kg) dry weight (dw); RAO 1 (human health seafood consumption)
- Dioxins/furans: 2 nanograms per kilogram (ng/kg) toxic equivalent (TEQ) dw; RAO 1 (human health seafood consumption)
- Arsenic: 7 milligrams per kilogram (mg/kg) dw; RAO 2 (human health direct contact)

[2] "**Natural Background**: substances present in the environment in forms that have not been influenced by human activity" (EPA 1989).

FS analyses showed that these PRGs are unlikely to be achieved for any remedial alternatives (e.g., see FS Section 9, Appendix A and Appendix J), due to the urban setting of the EW and sediment inputs from upstream of the LDW. Sediments accumulating in the EW contain concentrations of contaminants of concern (COCs) greater than natural background that are not related to EW sources, including inputs of suspended solids from the upstream Green River, general urban runoff from off-site upland impervious surfaces, storm sewer discharges, combined sewer overflow discharges, and other non-point sources. Therefore, the development of AB[3] values is needed:

> Generally, under CERCLA, cleanup levels are not set at concentrations below natural background levels. Similarly, for anthropogenic contaminant concentrations, the CERCLA program normally does not set cleanup levels below anthropogenic background concentrations (EPA 2002a).

Based on the aforementioned site-specific circumstances, EPA determined it necessary to develop AB estimates for total PCBs, dioxins/furans, and arsenic. These AB values will replace natural background-based PRG values presented in the FS in future EPA decision documents for the EW Operable Unit.

1.3 AB Estimation Approach

In late 2020, EPA and EWG held 13 meetings, with participation from the Muckleshoot Tribe and the Suquamish Tribe, to assemble and evaluate existing data, and then, if sufficient data existed, develop AB estimates for PCBs, dioxins/furans, and arsenic.[4]

The working group first reviewed the EW physical conceptual site model (CSM) with a focus on the relative contribution of different solids inputs to the EW. In the long term, following site remediation, the EW surface sediments will equilibrate to the solids characteristics of material entering the EW. Therefore, the approach used to develop the AB estimate was to identify existing datasets that would be representative of solids entering the EW that are not associated with site releases (Section 2). The assembled datasets were evaluated for acceptable quality and for adequate quantity for statistical evaluation. Ultimately, the working group focused on suspended solids inputs from the Green River based on data collected just upstream of the LDW; the Green River suspended solids data were deemed broadly representative of the upstream solids loading to the EW (Section 3).

Next, the Green River suspended solids dataset was further evaluated through a series of assessments (i.e., comparing different data treatment assumptions) to refine the dataset for use in estimating AB (Section 4). Key uncertainties were also assessed (Section 5). Finally, summary statistics for the selected AB dataset were calculated (Section 6).

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[3] "**Anthropogenic Background**: natural and human-made substances present in the environment as a result of human activities (not specifically related to the CERCLA release in question)" (EPA 1989).

[4] The Washington State Department of Ecology attended three meetings only for informational purposes.

2 Physical Conceptual Site Model

This section reviews aspects of the EW physical CSM documented in the FS that are relevant to this AB estimation. The primary sources of sediment to the EW are solids entering from the upstream Green/Duwamish watershed and from storm drain and combined sewer overflow (CSO) lateral[5] inputs (Figure 2-1). Geochronological coring indicates the EW is net depositional, receiving up to 4.2 centimeters (cm) of depositional material per year, with a site-wide average of approximately 1.2 cm per year (cm/yr). This newly deposited sediment is almost entirely (approximately 99 percent) made up of solids from the Green/Duwamish[6] River (Figure 2-2). Smaller portions of suspended sediment originate from the following: 1) lateral inputs, such as storm drains and CSOs, entering the EW along the EW itself (0.43 percent); 2) lateral inputs along the LDW that flow downstream into the EW (0.55 percent); and 3) LDW bed sediments that are resuspended and move downstream into the EW (0.24 percent; Figure 2-2). These estimated percentages of material settling in the EW are based on the future case estimates (FS Appendix J, Table 1, using a site-wide average deposition rate of 1.2 cm/yr),[7] which includes a reduction in solids inputs from EW laterals based on planned CSO control projects and source control actions in stormwater drainage basins. Sediment load into the EW from Elliott Bay is assumed to be very small compared to lateral inputs and was not included in depositional inputs in the CSM (FS Section 2.11.1).

Results from the LDW sediment transport model (QEA 2008) indicate that approximately 99 percent of the incoming upstream load to the EW from the Green River consists of silts and clays, as a result of more coarse fractions settling out in the LDW. This contrasts with the LDW, where coarse-grained particles make up approximately 33 percent of incoming sediment from the Green River, almost all of which deposits in the LDW. Figure 2-3 shows the relative change in grain-size composition during transport and settling in the LDW for the four particle size classes that were modeled in the LDW sediment transport model (QEA 2008).

In the long term (decades), surface sediments in the EW will equilibrate to incoming solids.~~, from the Green River, EW/LDW laterals, and resuspended LDW bedded sediment.[8] Although factors, such as sediment mixing (through propeller wash and bioturbation) and contaminated sediment remaining in the EW following remediation due to dredging limitations, will be important for assessing the EW site performance following remediation, they are not part of the AB evaluation, because they are~~

[5] "Lateral inputs" refers to outfall and small urban stream inputs located along the sides of the EW and LDW, consistent with the definition in the EW and LDW FSs. "Urban inputs" is used more generally to refer to EW and LDW laterals plus urban inputs to the Duwamish River upstream of the LDW.

[6] At the confluence of the Green and Black rivers, several miles upstream of the LDW, the name changes to the Duwamish River.

[7] The future case refers to the estimated solids loads to the EW following planned source control actions in lateral load drainage basins. Note that FS Appendix J, Table 1, was based on a site-wide average sedimentation rate of 1.6 cm/yr. However, the EW best-estimate sedimentation rate was later revised to 1.2 cm/yr; therefore, Appendix J, Table 1 values were revised to be based on 1.2 cm/yr for this document, consistent with the best-estimate values in the main body of the Final FS.

~~[8] Post-depositional processes, which are relevant to long-term arsenic concentrations, are discussed in Sections 4.4 and 5.6.~~

~~associated with the EW site.~~ The sources of solids entering the EW relevant to the AB estimate (Green River, EW/LDW laterals, and resuspended LDW bedded sediment) are discussed in the following sections.

2.1 Green River Inputs

The Green River originates in the Central Cascade Mountains and flows through 93 river miles of forested and developed lands, eventually becoming the Duwamish River and discharging into Elliott Bay in downtown Seattle. The Green/Duwamish River watershed is 300,000 acres and can be divided into four main subwatersheds: the Upper Green, the Middle Green, the Lower Green, and the Duwamish (Figure 2-4). The Upper Green and Middle Green are both predominantly forested subwatersheds, consisting of 95 percent and 57 percent forest land, respectively. The Lower Green and Duwamish are predominantly developed subwatersheds, consisting of 85 percent and 91 percent developed land, respectively (Conn et al. 2018a). The Howard Hanson Dam is located within the Upper Green subwatershed and regulates the flow of the Green River, maintaining minimum flows for salmon passage and restricting maximum flows for flood mitigation. Figures 2-5 and 2-6 present the land use and the stormwater and CSO drainage basins for the Green/Duwamish River watershed upstream and downstream of river mile (RM) 10.4, where multiple studies have been focused (Section 3).

Suspended solids in the Green River are from three main inputs, which are important for understanding the Green River component of EW AB. The first input includes solids that have accumulated behind and are released from the Howard Hanson Dam, particularly during large dam releases. The second input is associated with stormwater runoff that enters the Green River during precipitation events downstream of the Howard Hanson Dam, including into tributaries of the Green River. The third input is associated with the erosion of seams of certain geologic formations and resuspended bed sediment of Green River material downstream of the Howard Hanson Dam. These three sources vary over time in their relative contribution to Green River suspended solids inputs and contaminant concentrations due to varying river conditions (varying relative inputs from the Howard Hanson Dam discharges and stormwater runoff over time) (Conn et al. 2018a).

Figure 2-7 presents a histogram of average daily flows from 2001 to 2019 for the U.S. Geological Survey (USGS) flow gauge situated just below the Howard Hanson Dam (USGS station 12105900).[9] The flow discharge distribution shows lower flow conditions the majority of the time (the mode of the distribution is 275 cubic feet per second [cfs]), but with much higher average flows (981 cfs) and upper percentiles (90th percentile = 1,961 cfs). As noted previously, the Howard Hanson Dam maintains minimum flows for the Green River (with a minimum of 157 cfs observed in this dataset).

[9] 2001 to 2019 is the period that data were available for King County's Tukwila Rain gauge (ID TUKW), so it was selected for summary statistics.

Figure 2-8 presents precipitation for the same time period based on King County Tukwila rain gauge (ID TUKW). Similar to Howard Hanson Dam discharges, the distribution of precipitation is skewed, with no measurable precipitation the majority of the time. Days with more than 0.36 inch per day (in/day) occur 10 percent of the time (90th percentile of dataset). Figure 2-8 also presents summary statistics for days with more than 0.1 in/day to provide resolution on rainfall events at this same rain gauge location.

The sediment transport dynamics in the Green River and the LDW are also important for the EW AB estimate. Beginning at the LDW upper turning basin (RM 4.8),[10] the Duwamish River estuary widens, flow becomes slower, and the saltwater wedge from Elliott Bay becomes more influential. The upstream extent of the saltwater wedge varies over time from RMs 2 to 10 based on tidal and river flow conditions, with the most common extent occurring between RMs 2 to 4. A permanent saltwater wedge exists within the EW and upstream to approximately LDW RM 2.2. Because of these conditions, the LDW turning basin is a trap for depositing Green River suspended sediments and requires dredging every several years to maintain its function of capturing a large portion of the suspended solids to help maintain navigation channel depths further downstream. Coarse-grained suspended solids (sands) settle first, with finer-grained solids progressively settling out as water moves north toward Elliott Bay; thus finer-grained solids are largely what remains in suspension for transport toward the EW (although fine-grained solids do settle in the LDW). Some of the finer-grained solids entering the EW are ultimately transported to Elliott Bay.

Chemical datasets associated with Green River inputs are discussed in Section 3.1.

2.2 Urban Inputs

The Green/Duwamish Watershed becomes gradually more developed and industrialized moving northward toward Elliott Bay. Although the Green/Duwamish River receives stormwater from developed land upstream of the LDW (RM 5.0; Figure 2-5), this discussion is focused on urban inputs directly to the LDW and EW (i.e., EW and LDW lateral inputs), which represent approximately 1 percent of solids entering the EW. The EW and LDW lateral drainage basins are shown in Figure 2-6.

Urban runoff enters the EW/LDW through storm drains and CSOs associated with an extensive system of underground drainage pipes as well as creeks (LDW only). Suspended solids associated with these inputs are referred to collectively as lateral inputs. The drainage basin for the EW laterals, which is described in detail in EW SRI Section 9.4.3 (Windward and Anchor QEA 2014), includes three CSOs (Hinds, Lander, and Hanford No. 2) and 41 storm drain outfalls. CSOs only discharge during large storm events when the amount of water entering the combined sewer pipes exceeds the capacity of the system to transport all the flow to the wastewater treatment plants. The Lander and

[10] RMs are measured from the northern extent of the LDW Superfund site at the southern portion of Harbor Island.

Hanford No. 2 CSOs share most of the same drainage basin, with the Hanford No. 2 CSO draining slightly more area in South Seattle. The Lander and Hanford No. 2 CSOs combine to drain 5,000 acres, which is approximately 99 percent of the combined sewer drainage basin; the Hinds CSO accounts for the remaining 1 percent. A total of 788 acres around the EW drains through the EW storm drains, with the South Lander Street storm drain representing more than half (442 acres) of the total storm drainage basin area.

The LDW drainage basin is described in detail in LDW Remedial Investigation (RI) Section 9.4.4 (Windward 2010) and includes 10 CSOs, 5 emergency overflows, and 188 storm drains. Within the LDW drainage basin, the City of Seattle's municipal storm drain system services 61 percent of the LDW SD drainage basin, which is a separated or partially separated storm drain system, and unincorporated King County and City of Tukwila municipal storm drains service 24 percent of the drainage basin. The remaining 15 percent are serviced by private waterfront storm drain systems services.

The CSO and storm drain systems that discharge to the EW and LDW have been monitored, maintained, and upgraded over decades to reduce the discharge of contaminant inputs to waterways. These source control actions are ongoing, and additional source control is expected to occur.

EW FS Section 2.12 and LDW FS Section 2.4 describe source control activities in detail for these drainage basins. Source control activities include management of stormwater discharge regulated by the National Pollutant Discharge Elimination System, CSO control programs, compliance and inspection programs, EW and LDW source tracing activities and related actions (such as line cleaning), municipal stormwater management (including business inspections), upland site cleanup work, spill response programs, and air quality programs. Line cleaning, long-term infrastructure improvements, and improved maintenance and best management practices gradually reduce the solids mass and chemical concentrations entering the waterways. General urban inputs from permitted discharges will continue to occur. Chemical datasets associated with urban inputs are discussed in Section 3.2.

2.3 Lower Duwamish Waterway Bed Input

Approximately 0.2 percent of solids entering the EW are attributable to resuspended bedded sediments from the LDW (FS Section 5.1.1 [QEA 2008]), a very small fraction of the total solids load entering EW. In addition, cleanup of LDW bedded sediment has not yet been completed. Moreover, in the long term, following source control, sediment cleanup, and natural recovery of the LDW, COC concentrations in LDW surface sediments will become similar to loading inputs from the Green River and urban inputs from LDW laterals. Therefore, LDW bed load is not included in the AB evaluation, and chemical data are not discussed in Section 3.

3 Screening of Potentially Applicable Datasets

This section presents the datasets that were considered in the AB evaluation and provides the rationale for selecting the Green River suspended solids dataset to carry forward for further evaluation in Section 4. Available data were compiled and evaluated for adequacy, acceptability, and representativeness. These data quality categories are based on *Role of Background in the CERCLA Cleanup Program* (EPA 2002a), as adapted for this evaluation.

Adequacy addresses whether enough data are available to provide a reliable estimate of AB and is related to the number of chemical concentration measurements (sample counts).

Acceptability considers the data quality, including documentation, sampling procedures, laboratory procedures, and quality control (e.g., laboratory control samples such as matrix spikes, duplicates, and blanks). An acceptable study provides sufficient detail on field and laboratory methods to prove it is of acceptable quality to be included in the AB estimation. In the field, sampling must be performed using well-documented and well-established field sampling methods. Additionally, quality assurance/quality control samples must be analyzed to evaluate sample integrity and data quality. Each analyte must be measured by an accredited laboratory using EPA-approved methods. These laboratories must present detection limits and relevant data qualifiers. Finally, an appropriate level of data validation must be employed for each analyte considered in the AB estimation.

Representativeness is related to the CSM and considers if the data are characteristic of solids entering the EW. Representativeness was evaluated considering four different factors: geographical, temporal, physical, and land use. Geographical representativeness considers if the sampling location is appropriately selected for representing EW AB. The sampling should be reasonably close upstream of the EW but not be affected by known CERCLA releases. Temporal representativeness considers the age of the data (recent or historical), the time frame in which samples were collected (discrete sample or a time-weighted average), and the flow and precipitation conditions during sampling. Physical representativeness was evaluated by comparing particle size fractions from the samples to expected suspended solid particle size fractions that enter the EW. Land use representativeness considers the land use upstream of the sample compared to the land use upstream of the EW.

3.1 Green River Data

This section describes Green River investigations and screens Green River datasets.

3.1.1 Green River Investigations

The Green River has been the subject of multiple investigations over the past two decades to better understand contaminant loads moving into downstream LDW and EW Superfund sites.[11] These investigations have targeted three media of interest: suspended solids, surface water, and bedded sediment. The studies and the media sampled are listed as follows:

- USGS – Green River Loading Study (Conn et al. 2018a): suspended solids, surface water, and bedded sediment
- King County – Suspended Sediment Study (King County 2016), Green River Watershed Surface Water Data Report (King County 2018a), and Green River PCB Equipment Blank Study Data Report (King County 2018b): suspended solids, surface water
- Ecology – Contaminant Loading from Suspended Sediment (Ecology 2009) and Source Control Sediment Sampling (Ecology and Environment 2009): suspended solids and bedded sediment
- U.S. Army Corps of Engineers (USACE) – Turning Basin Sediment Core Sampling (Summarized in Windward 2020): bedded sediment
- Lower Duwamish Waterway Group (LDWG) – Compilation of Existing Data Report (Windward 2018), LDW Pre-Design Studies Data Evaluation Report (Windward 2020): surface water and bedded sediment from upstream of LDW

For the dataset screening, the reports for these studies were reviewed, and the data from each study were compiled. Some of the data had already been compiled by LDWG for the LDW FS (AECOM 2012), the Compilation of Existing Data Report (Windward 2018), and the Pre-Design Studies Data Evaluation Report (Windward 2020). Data were also acquired from Ecology's Environmental Information Management database and from King County's Environmental Laboratory Information Management System. Table 3-1 presents the sample counts by study for the Green River datasets, Table 3-2 summarizes the dataset screening by medium (suspended solids, surface water, and bedded sediment), and Table 3-3 provides a detailed evaluation of the Green River suspended solids datasets. The studies are summarized in the following paragraphs.

The USGS Green River loading study collected suspended solids, surface water, and bedded surface sediment from 2014 to 2017 at RM 10.4 (at the Foster Links Golf Course). Suspended solids and surface water were collected during 42 discrete sampling periods targeting a variety of flow conditions, as described in Table 3-3. Suspended solids were collected over 24 to 48 hours using centrifugation. In addition, on seven occasions a bedded surface sediment composite sample was collected within 1,000 meters downstream of RM 10.4.

[11] The exception is the LDW upper turning basin core sampling from the U.S. Army Corps of Engineers (USACE), which was sampled for the purpose of evaluating dredge material quality in the upper turning basin of the LDW but which is included in this screening as potentially relevant to AB determination.

The King County suspended sediment study collected suspended solids by filtering surface water (filter solids) or using sediment traps (baffle-style and jar-style) at four locations in the Green River Watershed from 2012 to 2015. Only the samples collected at RM 10.4 were considered for this evaluation, because it is downstream of the other sampling locations and is the same location as the USGS study (totaling 12 filter solids samples and 9 sediment trap samples). Filtered suspended solid samples were collected over 24 to 48 hours, while sediment trap samples were collected following an approximately 3-month deployment period. King County also collected surface water samples from various locations within the Green River Watershed.

Ecology conducted two investigations focused on the collection of suspended solids (Ecology 2009) and bedded sediment (Ecology and Environment 2009). Collection of suspended solids at RM 6.8 occurred approximately monthly over a 7-month period in 2008 and 2009 (seven sampling events). Collection of suspended solids from the water column by continuous-flow centrifugation occurred over 24 or 48 hours. Bedded sediment samples were collected from 104 locations from RM 4.9 to RM 6.5 over a 10-day period in 2008.

USACE performs dredge material characterization testing of sediment in the upper turning basin of the LDW prior to periodic maintenance dredging. Data from sediment core composite samples collected in 2008, 2009, 2011, and 2017 were compiled by the LDWG in the LDW Pre-Design Studies Data Evaluation Report (Windward 2020).

The upper turning basin is located at the upstream end of the LDW Superfund site, but functions as a trap, capturing approximately one-third of the sediment entering the LDW from the Green/Duwamish River.

~~and was therefore considered in this analysis.~~ LDWG has compiled data and performed sampling of surface water and sediment of the Green River upstream of the LDW Superfund site. The LDWG Pre-Design Studies Data Evaluation Report presents surface water samples collected by the LDWG at RM 10.4 for eight sampling events from August 2017 to July 2018. Surface water sampling by King County prior to 2011 are also included in the LDWG compiled data. Additionally, 37 bedded sediment samples upstream of the LDW were compiled by LDWG for the LDW RI (see LDW FS Appendix C, Part 3b; AECOM 2012).

3.1.2 Green River Datasets Screening

Data were aggregated by media (suspended solids, surface water, and bedded sediment) and then evaluated for acceptability, representativeness, and adequacy. As presented below, suspended solids were retained as the applicable Green River dataset, and surface water and bedded sediment were eliminated based on representativeness evaluations for the applicable Green River dataset.

3.1.2.1 Suspended Solids Datasets

The suspended solids datasets were retained based on adequacy (Table 3-1), acceptability (Table 3-2), and representativeness (Table 3-2).

For acceptability, the suspended solids sampling programs by USGS, King County, and Ecology were all performed using well-documented sampling procedures and well-established and validated laboratory procedures. All three sources of data were of acceptable quality to be further evaluated (Table 3-3).

For geographical representativeness,[12] suspended solids data collected from RM 6.8 and RM 10.4 were both considered geographically representative because they are upstream of the EW and LDW Superfund sites. RM 10.4 is upstream of the salt wedge and is therefore representative of Green River suspended solids transporting toward the EW. RM 6.8 has a periodic salt wedge, but Ecology sampling was performed to avoid sampling saltwater (Table 3-3).

For temporal representativeness, all suspended solids data were considered to be sufficiently recent (sampled within the past 15 years) for inclusion. Each suspended sediment sampling program collected samples during a variety of flow and precipitation conditions so that their datasets would be representative of periods with different river conditions within the Green River. This is important because different river conditions can result in different suspended solids chemical concentrations (Table 3-3).

For physical representativeness, suspended solids samples were primarily fine-grained and therefore considered sufficiently representative of fine-grained sediment that deposits in the EW. Sediment trap samples, which are more coarse-grained than centrifuge and filter solids samples, are evaluated further in Section 4.

For land use representativeness, because the Green River Watershed provides roughly 99 percent of solids that enter the EW, the land use upstream of these sampling locations (RM 10.4 and RM 6.8) are considered generally representative. Solids inputs downstream of these sampling locations, particularly from within the LDW and EW Superfund sites, are discussed in Section 3.2.

Based on this evaluation, all suspended solids datasets were considered acceptable and representative and therefore were retained for the AB evaluation, resulting in 59 to 82 samples (depending on the analyte). This number of samples was considered adequate for further AB evaluations in Section 4.

3.1.2.2 Surface Water Datasets

The surface water datasets consisted of whole -water samples for PCBs and dioxins/furans and both whole -water (total) and filtered (dissolved) samples for arsenic. The surface water samples were collected,

[12] Geographical representativeness in this memorandum refers to a physical location that is representative of solids that enter the EW (i.e., upstream solids) rather than a similar environmental setting.

analyzed, and validated using acceptable methods. However, the datasets were not considered representative due to uncertainty in the solids estimate calculation, as described below (Table 3-2).

Surface water data were evaluated using the approach previously employed in the LDW FS Appendix C, Part 3b (AECOM 2012) for estimating Green River inputs to the LDW. Hydrophobic organic compounds, such as PCBs and dioxins/furans, are primarily associated with particulates (through partitioning to organic carbon). Therefore, concentrations in unfiltered whole-water samples can be divided by the sample's total suspended solids concentrations to estimate the particulate concentration in surface water sample. However, because some portion of these compounds can also be associated with colloids[13] as well as exist in freely dissolved fraction, the resulting particulate concentration estimate is biased high.

For arsenic, which includes a larger dissolved component than hydrophobic organics, the filtered water concentrations (dissolved arsenic) were subtracted from unfiltered concentrations (total arsenic) to estimate each sample's particle-bound fraction prior to dividing by the sample's total suspended solids concentration. However, this calculation relies on combining three different analytical results, which compounds variability in the calculated result, reducing representativeness.

In summary, the surface water datasets are of acceptable quality and adequate sample numbers, but the method for calculating suspended solids concentration introduces potential bias and uncertainty. This, combined with the more representative and adequate number of suspended solids samples, resulted in the elimination of the surface water datasets from further AB evaluations.

3.1.2.3 Bedded Sediment Datasets

Green River and LDW turning basin bedded sediment data were collected, analyzed, and validated using acceptable methods. However, these data did not meet representativeness standards (Table 3-2). Bedded surface sediment from the Green River and the LDW Turning Basin has coarser particle sizes compared to that which enters the EW. For this reason, bedded sediment data within the Green River and the LDW turning basin are not considered representative of material that would eventually reach the EW and are not carried forward to Section 4.

3.2 Urban Input Data

This section discusses inputs from urbanized drainage basins that are not captured in the Green River data described in Section 3.1. Urban inputs that are not part of a known CERCLA release are an important component of AB (EPA 2002b). Urban inputs include contributions from the drainage basin to the Duwamish River downstream of RM 10.4 and contributions from the LDW and EW direct drainage basins. These include both general urban inputs that will persist in the long term and

[13] Total suspended solids are typically determined using a 0.45-micrometer filter that does not capture colloids (particulates smaller than filter size).

known CERCLA releases that will be controlled prior to sediment cleanup, which comingle and cannot be easily separated from each other.

Data were not readily available for lateral inputs above the LDW (RM 5.0), but all the urban areas downstream of the Green River sampling locations (at RM 10.4 and RM 6.8) contribute urban runoff that influences AB for the EW.

Section 2.2 describes the EW and LDW lateral drainage basins where lateral input data have been collected. Solids samples collected directly from storm drains or CSOs (catch basin, in-line grab samples, or in-line sediment traps) have been used in the past to estimate urban inputs. The available datasets for lateral solids are presented in the EW SRI (Appendix I) and EW FS (Appendix B, Part 4), and the laterals datasets for the LDW have recently been aggregated in the *Lower Duwamish Waterway Pre-Design Studies Data Evaluation Report* (Windward 2020). These laterals datasets are representative of current conditions (see Appendix A, Part 3, of this document). In addition, these data meet acceptability standards and are of adequate quantity to characterize this input.

As noted in Section 2, the solids mass entering the EW from both EW and LDW drainage basins is low (predicted to be less than 1 percent). However, estimating chemistry concentrations following source control (representing solids inputs not related to CERCLA releases for the drainage basins)[14] is uncertain. Because of the relatively small solids contribution and uncertainty in future chemistry concentrations of urban inputs, the lateral input dataset is not considered further in establishing AB.

[14] Additional source control actions will occur in the future to ensure sources are sufficiently controlled to proceed with sediment cleanup actions.

4 Green River Suspended Solids Data Assessment

The previous section screened potentially relevant datasets, concluding that suspended solids data from samples collected in the Green River at RM 10.4 and RM 6.8 would be retained for further assessment in the AB estimate. The suspended solids dataset is provided in Appendix B. This section discusses the following factors that were assessed in developing a final dataset for estimating AB value:

- Comparison of sampling methods (centrifuge, filter solids, and sediment traps)
- Analyte-specific considerations such as analytical methods (total PCBs congeners versus Aroclors), summing procedures (non-detect treatment), and dioxin/furan congeners selection~~, and arsenic biogeochemical processes~~
- Outlier assessments
- Particle size distribution adjustments
- River flow condition and precipitation weighting

4.1 Sampling Methods

The following three methods were used to sample suspended solids in the Green River.

- 44 samples collected by centrifugation (USGS and Ecology)
- 12 samples collected by filtration (King County)
- 9 samples collected by sediment trap using jar-style or baffle-style traps (King County)

Detailed information on these methods is provided in the source documents for the USGS, King County, and Ecology investigations (see Section 3.1.1).

Centrifuge and filtration sampling methods both rely on pumping river water over a 24-to-48-hour period to collect solids, targeting a range of river conditions over multiple sampling events. The two sediment trap sampling methods both involve the passive collection of solids over a 3-month period. The suspended solids collected by centrifuge and filter methods typically consisted of finer-grained material compared to sediment traps. Sediment traps, which collect solids closer to the sediment bed, retain coarser-grained suspended solids and also sediment bedload. Table 4-1 presents summary statistics for the percent fines for the different sampling methods; the average percent fines is 48 percent for sediment traps, compared to 75 percent for centrifuge and filter solids samples. Fine-grained suspended solids are representative of material that is more likely to reach the EW; coarser-grained suspended solids are representative of material that is more likely to settle in the LDW.

Coarser-grained material generally has lower contaminant concentrations than finer-grained material for all three contaminants of interest. In particular, organic contaminants (total PCBs and dioxins/furans) tend to sorb to the organic carbon on the particle surface. As particle sizes decrease, the surface area-to-mass ratio increases, resulting in higher relative concentrations of organic carbon, and therefore organic contaminants, on smaller particles (Hedges and Kiel 1995; Karickhoff et al.

1979; Wang and Keller 2008). As a result, the sediment trap concentrations are likely biased low compared to the centrifuge/filter solids concentrations. Mean concentrations for sediment traps are roughly half of the mean centrifuge/filter solids concentrations (sediment traps are 50 percent of centrifuge/filter solids for total PCBs, 36 percent for dioxin/furan TEQ, and 57 percent for arsenic [Figure 4-1 and Table 4-1]).

Sediment trap data were excluded from the dataset used to define AB, due to this systematic higher sand content that is less representative of solids entering EW and results in biased low concentrations of sediment trap samples. The effect this exclusion has on AB calculations is considered as part of the sensitivity analysis in Section 5.

4.2 Total PCBs

4.2.1 Total PCB Aroclors

The 66 centrifuge/filter solids samples were analyzed for PCBs using either EPA Method 8082 (Aroclors), EPA Method 1668A/C (congeners) or, in some cases, both methods, detailed as follows:

- 7 samples: Aroclors only
- 32 samples: congeners only
- 17 samples: both methods

The PCB congener method produces lower detection limits and greater accuracy at low concentrations than the Aroclor method. For example, 8 of the 17 samples analyzed using both methods were non-detect for all Aroclors but contained detectable concentrations of some congeners.[15] For this reason, where both methods were used, only the total PCB congener results were retained.

Seven samples were analyzed for Aroclors only. Although detection limits were relatively low for these samples (2.7 µg/kg or less), no Aroclors were detected in three of seven samples. Furthermore, the mean total PCB concentrations for centrifuged/filtered samples with and without these seven Aroclor samples were essentially the same (Table 4-2). Therefore, the PCB congener dataset (n = 49) was considered adequate without including the seven samples analyzed for Aroclors only.

Based on this assessment, only the congener data were retained for AB estimation. The effect this exclusion has on AB calculations is discussed in the sensitivity analysis in Section 6.

[15] EPA Method 1668A/C analysis includes 209 PCB congeners.

4.2.2 Total PCB Congener Summing Methods

Method EPA 1668A/C analyzes for 209 congeners, which are reported as more than 150 individual and co-eluted PCB congeners. These data are summed to calculate total PCBs. Every sample has some non-detected PCB congeners, so the effect of non-detect value treatment was evaluated for the dataset.

Four non-detect treatments for summing PCB congeners were evaluated. Three consisted of substitution of the non-detected reported value as follows: 1) assuming non-detect values equal 0; 2) assuming non-detect values equal half the reported value; and 3) assuming the non-detect values equal the reported value. The reported value for non-detects is typically equal to the sample specific detection limit for these studies, although a different value can be selected based on the data validation. In each of these three cases, on a sample basis, total PCBs are based on sum of the detected congeners and the non-detect treatment described. The fourth non-detect treatment was based on Kaplan-Meier estimation for the non-detected values for each congener within each sample with Efron's bias correction, based on the method described in the memorandum regarding *Modified Approach for Calculating Total Concentrations of PCBs and PAHs, Bradford Island Remedial Investigation, Cascade Locks, Oregon* (URS 2010). The Kaplan-Meier mean was computed for each sample based on the concentrations of detected values and the Kaplan-Meier estimation for non-detects. The sample mean was then multiplied by the number of congener analytical results to calculate the total concentration for each sample.

Different treatments of the non-detects had almost no effect on total PCB congener concentrations (Table 4-3), likely due to the high number of detected congeners in each sample. To remain consistent with the EW SRI and FS, assuming non-detect values equal 0 was selected as the non-detect treatment for the dataset.

4.3 Dioxins/Furans

4.3.1 Congener Selection

Dioxin/furan results consist of 17 congeners. Of these, four were determined to be the primary contributors of the risk associated with seafood consumption (the RAO for which background concentration was used as a PRG in the FS). Specifically, these four congeners make up 86 percent of adult/child tribal seafood consumption dioxin/furan risk and 82 percent of adult Asian Pacific Islander seafood consumption dioxin/furan risk.[16] Therefore, these four congeners were selected for the development of AB values for use in establishing cleanup levels associated with seafood consumption pathway. The four selected congeners are as follows:

[16] These percentages were developed without including the portion of risk from clam/geoduck because of the very low frequency of detection of dioxin/furan congeners in these tissues.

- 2,3,7,8-TCDD
- 2,3,7,8-TCDF
- 1,2,3,7,8-PeCDD
- 2,3,4,7,8-PeCDF

Dioxin/furan congener concentrations are converted to dioxin/furan TEQ to estimate risk to human health.[17] Dioxin/furan TEQ concentrations are presented in this document as a summary metric to provide continuity with SRI/FS documents and to support risk communication. The dioxin/furan TEQ is also used in evaluations in Section 5 as representing the four dioxin/furan congeners (i.e., the data analysis trends for individual congeners are generally the same as for dioxin/furan TEQ).

4.3.2 Non-Detect Treatment

Dioxin/furan congeners were detected in most of the suspended solids samples. However, because there were a few non-detected congeners for some samples, the effect of the non-detect treatment on congener summary statistics was explored for the AB estimate.

Four non-detect treatments for summing dioxin/furan congeners were evaluated. Three consisted of substitution of the non-detected reported value as follows: 1) assuming non-detect values equal 0; 2) assuming non-detect values equal half the reported value; and 3) assuming the non-detect values equal the reported value. The fourth non-detect treatment was based on a regression on order (ROS) estimation of non-detects for the population.

Out of 54 samples, at least one of the four dioxin/furan congeners were detected in 42 to 46 of the samples. Setting non-detect values to half the reported value resulted in a mean that was similar to the mean calculated using an ROS estimation for all congeners (Table 4-4). Setting non-detect values at 0 times the reported value or at the reported value bracketed these other two methods.

Based on this analysis, both half the reported value and the ROS estimation method of non-detects are reasonable methods for non-detected values for summary statistics because they provide similar results and are in the middle of the lowest and highest possible values. From this analysis, 0 times the reported values would bias the results slightly low, and 1 times the reporting limit would bias the results slightly high.[18] The ROS estimation method for non-detects was carried forward for use in summary statistics for four dioxin/furan congeners in this document.

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[17] The TEQ method weighs each congener in a manner proportional to its relative toxicity to 2,3,7,8-TCDD, based on the TEQ for each congener (Van den Berg et al. 2006), as described in the EW Baseline Human Health Risk Assessment (SRI Appendix B).

[18] This is a different result than summing PCB congeners (Section 4.2.2), for which 0 times the detection limit was selected as the appropriate method for summing. The difference is due to the data characteristics and the purpose of the non-detect estimate. Non-detect treatment for PCBs was used for summing many (>150) congeners for each sample with very low detection limits, and the non-detect treatment had almost no impact on sample sums. In contrast, the non-detect treatment for dioxins/furans was used for calculating summary statistics for the population of samples for each congener and had a slight effect on results.

4.4 Arsenic

Arsenic was analyzed in 52 samples by analytical methods EPA 6020 or 200.8. Arsenic was detected in all samples, so evaluation of non-detects was not needed for AB evaluation. However, the AB evaluation dataset indicates a higher arsenic concentration in suspended solids (mean of 17.2 mg/kg for centrifuge/filter solids) than the concentration of bedded sediment in the EW (mean of 11 mg/kg for the FS baseline dataset~~; Table 4-5~~). Arsenic in Green River suspended solids likely comes from natural and anthropogenic sources such as historical pesticide use. ~~The arsenic in Green River suspended solids are most likely attributable to contributions from natural (geogenic) arsenic sources. Arsenic mineralization has been documented in several areas within the Green River upstream of the EW (Royal Reward Mine [https://www.mindat.org/loc-4215.html]).~~

~~Table 4-5 compares the arsenic concentrations in the AB dataset (Green River suspended sediment centrifuge/filter solids samples) with arsenic concentrations in bedded sediment in the EW, and in twothree completed sediment cleanup sites in West WaterwayElliott Bay and LDW (post-remediation conditions evaluated during long-term monitoring).), and in Elliott Bay. Mean concentrations in Elliott Bay bedded sediments and nearshore cleanup sites range from 6.0 to 9.6 mg/kg.~~

~~Concentrations associated with bedded sediment are influenced by biogeochemical conditions that affect the partitioning behavior and mobility of arsenic, both in the water column and in sediment (Fendorf et al. 2010; Campbell and Nordstrom 2014). Arsenic partitioning from particles to water is enhanced by increasing pH and salinity in the water column. Arsenic can also be mobilized from deposited sediment particles under reducing conditions. These complex biogeochemical processes can result in the release of arsenic into the dissolved phase both from suspended particles in the water column and from deposited sediment. PCBs and dioxins/furans are comparatively inert to these mechanisms. The effects of post-depositional biogeochemical processes are difficult to predict and therefore were not incorporated into the AB estimate for arsenic.~~

The arsenic AB value was calculated based on Green River suspended solids (centrifuge/filter solids)~~),~~ because suspended solids are an accurate representation of material entering and settling in the EW. The influence ~~these~~ biogeochemical processes may have on arsenic concentrations in EW sediments are discussed ~~further~~ in Section 5.8.

4.5 Outlier Evaluation

This section discusses whether any of the analytical data should be qualified as outliers and removed from the dataset. EPA guidance defines outliers as measurements that are unusually larger or smaller than the remaining data. They are not representative of the sample population from which they are drawn (EPA 2002b).

As shown in Figure 4-1, some of the higher centrifuge/filter solids concentrations are well above the median and inner quartiles of the datasets. These data were examined as potential outliers in the following two ways: 1) consideration of whether the data were consistent with the Green River CSM; and 2) consideration of whether the data were consistent with statistical distributions that might underlie the dataset.

4.5.1 Conceptual Site Model Outlier Evaluation

The highest concentrations in the dataset were considered for reasonableness based on flow and precipitation conditions during their collection and the Green River CSM for how these conditions affect contaminant concentrations. As discussed in Section 2.1 and Appendix A, Part 1, of this document, the following three main sources of suspended solids affect concentrations: 1) releases from the Howard Hanson Dam; 2) stormwater runoff; and 3) and erosion from the streambed of the Green River. These three sources vary in concentration of the three contaminants and vary in their relative influence on the suspended solids concentration at any given time, largely based on precipitation and river flow conditions. All three contaminants have lower concentrations associated with substantial dam releases,[19] which results in high flow conditions. The organic contaminants, PCBs, and dioxins/furans have higher concentrations related to stormwater runoff due to diffuse urban sources. In contrast, arsenic concentrations tend to be higher during baseflow[20] conditions without precipitation and runoff. This is likely attributable to less dilution of naturally occurring arsenic associated with Green River bed material, as discussed in Section 4.4.

Table 4-5~~6~~ presents the five centrifuge/filter solids samples with the highest concentration for each contaminant, the month and season of sampling, the river flow, and the precipitation conditions for each. Consistent with the Green River CSM, the five highest PCBs and dioxins/furans concentrations occurred during high precipitation/runoff and low-flow events. Precipitation for these events was in the upper 77th percentile or higher, and flow was in the 69th percentile and lower.

Also consistent with the CSM, the highest arsenic concentrations occurred during low flow conditions (38th percentile or less). Four of five higher concentrations occurred during no-precipitation events; one sample broke from the pattern and was in the 86th percentile for rainfall. All higher-concentration events were in the later summer and early fall.

Based on this evaluation, the samples with the highest concentrations were consistent with the Green River CSM and are not considered outliers in this context. The highest PCBs and dioxin/furan concentrations occur during low river flow and high precipitation conditions (due to a larger impact of stormwater inputs during these times). The highest arsenic concentrations occur during low river

[19] As adopted by USGS (Conn et al. 2018a) and King County (2016) studies, substantial dam release (termed "significant" dam releases in the reports) is considered 2,000 cfs or greater at the base of the Howard Hanson Dam.
[20] Baseflow is when there are lower river flows without precipitation events.

flow and low precipitation conditions (due to a larger impact of natural Green River sources described in Section 4.4 during these times). This analysis does not indicate the presence of any outliers.

4.5.2 Statistical Distribution Outlier Evaluation

The AB dataset was also compared to applicable statistical distributions to assess if high or low concentration samples represent a break with the apparent underlying distribution of the data. Statistical distributions were evaluated graphically using quantile-quantile (Q-Q) plots (Figure 4-2) and mathematically with distribution selection testing.[21] Consistent with the visual evaluation, all three contaminants were identified as log-normally distributed.

If present, high outliers would be located to the upper left of the diagonal line, and low outliers would be located to the lower right of the diagonal line of the Q-Q plots. As shown in Figure 4-2, all values roughly follow the diagonal, indicating the distributions are consistent with the log-normal distribution. This analysis does not indicate the presence of any outliers.

4.6 Particle Size Distribution in Suspended Sediment

A well-established theoretical and empirical relationship exists that shows organic contaminants more strongly associated with finer-grained particulate matter than with coarser-grained sediments (Hedges and Kiel 1995; Karickhoff et al. 1979; Wang and Keller 2008). Organic carbon sorbs on the surface of particles and therefore accumulates in proportion to the surface area of particles. Particulate organic matter also occurs in a range of particle sizes. Organic contaminants bind to particulate organic matter as well as the organic carbon sorbed on particle surfaces. Because smaller particles have a larger surface area-to-mass ratio than larger particles, the finer particles also accumulate higher concentrations of organic contaminants. This relationship does not apply to metals.

Empirically, this trend was observed in the suspended solids dataset, with samples with higher fines having higher organic contaminant concentrations on average. This trend was also observed in the USGS bedded sediment samples, which were analyzed for contaminant concentrations in bulk sediment as a whole, as well as in the sieved fines fraction (Conn et al. 2014, 2015).

Centrifuge/filter solids suspended solids samples ranged from 44 percent to 95 percent fines; however, solids entering the EW are predicted to be 99 percent fines in the LDW sediment transport model (QEA 2008). During transport from the Green River through the LDW, the coarser-grained suspended solids settle out first, as seen with sands largely settling in the LDW upper turning basin and finer material progressively settling out as water moves north toward Elliott Bay. The sediments transported through the LDW reaching the EW are essentially the fine-grained sediments (Figure 2-3; QEA 2008). The progressive settlement of more coarse sediments at the south end of the LDW and

[21] The Shapiro-Wilk test was implemented in the distChoose function by the EnvStats package for the R software environment.

movement of essentially fine-grained suspended solids into the EW results in a gradual increase, per unit mass, of organic contaminants present in suspension compared to what is present in suspension at RM 10.4, where the AB dataset was sampled. This results in a low bias of the concentrations measurement of suspended solids at RM 10.4 compared to what enters the EW. The following three potential methods to adjust the AB dataset to address this were explored in this analysis:

1. Excluding samples with low fines
2. Fines normalization
3. Particle surface area adjustments

Each of these methods is discussed in the following sections.

4.6.1 Excluding Samples with Low Fines

The first and simplest method for adjusting for the progressive fining (the process whereby coarser material settles out and finer material remains in suspension) of suspended sediment during transport from the Green River to the EW was to exclude suspended solids samples with low-percent fines from the AB calculation. The distribution of samples with percent fines was analyzed to identify potential threshold values for screening the dataset. A threshold value of 60 percent fines was selected to balance the competing needs of excluding samples with the lowest fines content and maintaining a large sample size in the remaining dataset. The 60 percent fines threshold value results in removal of the lower quartile from the dataset (approximately 25 percent of samples were screened out).

Excluding samples with low fines content from the dataset is a simple way to account for the low bias in the dataset. However, the method reduces the total number of samples in the dataset, and the remaining dataset on average still contains a lower percent fines (77 percent on average) than the approximately 99 percent fines entering the EW.

4.6.2 Fines Normalization

Fines normalization retains all samples in the analysis and adjusts each sample concentration in proportion to the percentage of fine-grained material in the sample. Mathematically, fines normalization consists of dividing the concentration by the fraction of fines in each sample as follows:

$$Concentration_{fines-normalized} = \frac{Concentration_{dry-weight}}{Percent\ fines/100}$$

Physically, this equation assumes that all contaminant mass is in the fine-grained fraction of suspended solids, which is the fraction that enters and deposits in the EW.

Fines normalization has the advantage of retaining all the data and adjusting each datapoint according to the characteristics of each sample. The fines normalization approach has a few limitations based on assumptions imposed by the calculation method. The equation may over-adjust for particle size distribution by not attributing any contamination to the sand fraction, which contains a smaller portion of the total contamination of the sample. However, the equation may also under-adjust for particle size distribution because the equation does not account for contaminant concentration differences within the fines category (i.e., the difference between clays and silts). For instance, an increase in the clay fraction entering the EW compared to that measured in the Green River suspended solids will have a larger effect on concentration than an increase in silts.

4.6.3 Particle Surface Area Adjustments

A third method was developed to adjust concentrations based on trends in contaminant concentrations associated with various particle size fractions. This adjustment accounts for the relative particle size distribution between the Green River and the EW, and considers the fact that the area available for organic contaminant binding to a particle is proportional to the surface area of that particle (Hedges and Kiel 1995; Karickhoff et al. 1979; Wang and Keller 2008). As particle size increases, the relative mass (which is directly proportional to the volume of the particle) increases more relative to the increase in surface area. The particle surface area adjustment calculation is provided in Appendix A, Part 2, of this document.

The surface area method is consistent with the physical model for the transport of suspended solids in the Green River, the LDW, and the EW. The method accounts for concentrations in the sand fraction and for changes in concentration between four particle size categories. The drawback of the surface area method is that it relies on modeling and empirical relationships that are not directly measured in the Green River suspended solids dataset, and would be challenging to measure empirically.

4.6.4 Summary of Particle Size Distribution Adjustments for Organic Contaminants

Three particle size distribution adjustment methods were developed to account for the concentration enrichment expected to occur when coarser material settles out and finer material remains in suspension during transport from the Green River through the LDW to the EW. Excluding data with low (<60 percent) fines reduced the size of the dataset and did not fully account for the change in particle size during transport to the EW. The surface area adjustment method accounts for particulate contaminant concentrations in different grain -size fractions and captures the change in particle size but relies primarily on empirical relationships and modeling. Therefore, it includes additional assumptions that increase the analysis uncertainty. Fines normalization is subject to less uncertainty, as it relies on fewer assumptions while also acknowledging the difference between Green River suspended solids grain sizes compared to the grain sizes that enter the EW. Excluding data with low -percent fines and the surface area adjustment method are included in the sensitivity analysis presented in Section 5.

4.7 River Flow and Precipitation Weighting

As discussed in Sections 2.1 and 4.5.1, the concentrations of contaminants in suspended solids vary with river conditions. River gauge flow measurements from below the Howard Hanson Dam and precipitation gauge measurements near suspended solids sampling locations prior to and during sampling provide a method to assign suspended solids data by the conditions that affect chemical concentrations. Because samples were collected during different flow and precipitation conditions, they may be more or less representative of the overall average conditions in the Green River. Therefore, a flow and precipitation weighting calculation was developed to group and weight samples based on the prevalence of different flow and precipitation conditions in the Green River (Appendix A, Part 1, of this document).

A weighted average concentration was calculated based on the contaminant average concentrations and the amount of time that the Green River is in each of four river flow/precipitation conditions. These four conditions were binned into the following: low flow/low precipitation; high flow/low precipitation; low flow/high precipitation; and high flow/high precipitation (see Appendix A, Part 1). Each sample was placed into one of the four bins based on the conditions during sampling. The average concentration of samples for each of the four conditions was multiplied by the fraction of time each condition occurred over the time period from 2001 to 2019 (the selected time period with available river flow and precipitation data from the gauges) to get a weighted average concentration.

The analysis was not used to establish AB concentrations because of uncertainties and assumptions that are part of the calculation process and flow/precipitation binning methodology. In addition, the methodology effectively reduces the sample size to what is present in each individual bin. However, the river flow and precipitation weighting method was retained as a sensitivity run in Section 5 in order to evaluate the effects of adjusting the suspended solids concentrations following the Green River CSM.

4.8 Selected Data Treatment for the AB Dataset and Calculation

Sections 4.1 through 4.7 detail a number of assessments that help understand the effects of different data treatments on the AB dataset. From these assessments, the following data treatments were selected for AB estimation:

- Use centrifuge and filter solid samples only (exclude sediment traps)
- Use PCB congener data only (exclude all Aroclor data)
- Use only detected PCB congeners in summing (non-detected congeners equal to 0)
- Calculate AB for the four dioxin/furan congeners that are primary contributors to human health seafood consumption risk (while also presenting the dioxin/furan TEQ for informational purposes) and use ROS for non-detects summary statistics for non-detected results
- Perform fines normalization for organic contaminants to account for particle size differences between Green River samples and suspended solids flowing into the EW

- All centrifuged and filtered solids sample data used without any adjustment for arsenic

Section 5 presents the sensitivity analysis associated with these analyses, and Section 6 presents the statistics for the AB dataset.

5 Uncertainty

Multiple assessments of the Green River suspended solids dataset were explored in the development of the AB dataset and calculation methods. This section compares the results of those assessments and their effect on AB estimates in a sensitivity analysis and discusses additional uncertainties related to the AB evaluation. Sections 5.1 through 5.5 discuss uncertainty factors that were quantitatively evaluated in the sensitivity analysis, and Sections 5.6 through 5.8 discuss uncertainty factors that were evaluated qualitatively.

5.1 Sensitivity Analysis Results Summary

The sensitivity analysis identifies the magnitude of changes to the AB estimate when changing a single component of data selection or data treatment, while keeping all other variables constant.

Figure 5-1 provides a graphical depiction of the sensitivity analysis. The mean concentrations resulting from each sensitivity component are compared to the mean concentration of the unadjusted AB dataset.[22] Negative percentages on the figure indicate a reduction in the mean concentration, and positive percentages indicate an increase in mean concentration. Zero denotes no change from the mean concentration.

The results range from a reduction in concentration of up to approximately 20 percent (using river flow/precipitation conditions weighting for total PCBs) to an increase of approximately 66 percent (using the surface area method of particle size adjustment for both total PCBs and dioxins/furans). Table 5-1 provides the numerical results. The sensitivity analysis results are discussed further in the context of uncertainty discussions in the following sections.

5.2 Exclusion of Sediment Trap and Total PCB Aroclor Samples

This section documents the impact of excluding sediment trap or PCB Aroclor samples as described in Sections 4.1 and 4.2.1. Including sediment trap data would decrease average concentration of the dataset by 8 percent (total PCBs), 5 percent (dioxins/furans), and 6 percent (arsenic). Concentrations in sediment trap data are low compared to the centrifuge and filter solids samples, because sediment traps contain a higher percentage of coarse-grained solids that are associated with lower chemical concentrations (Section 4.1; Figure 4-1 and Table 4-1). The sensitivity calculations also show that including the samples with Aroclor-only data results in a 2 percent decrease in average concentration in the dataset. This small change is due to the small number of samples (n = 7), and the similar mean concentration in the Aroclor-only dataset compared to the mean of the congeners-only dataset (Table 4-2).

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[22] The sensitivity analysis varies one component at a time compared to the AB dataset without grain size adjustment, consistent with the sensitivity analysis methodology.

5.3 Non-Detect Treatments

Non-detect treatments for total PCB summing and dioxin/furan summary statistics were evaluated in Sections 4.2.2 and 4.3.2. AB concentrations are not sensitive to non-detect treatment. The effect of non-detect treatment can be further minimized by applying identical treatments to EW site samples during comparisons to AB.

5.4 Dioxin/Furan Congener Selection

AB estimates are established for four of 17 dioxin/furan congeners. These four congeners contribute the majority of the dioxin/furan seafood consumption risk (82 percent to 86 percent; Section 4.3.1). The other congeners each represented 7 percent to <1 percent of the risk (based on TEQ contribution to fish and crab tissues). This small contribution of each indicates AB for the four congeners will be representative of most of AB contribution to risk. Thus, only a small uncertainty exists for developing AB for four of 17 dioxin/furan congeners. In addition, all 17 dioxin/furan congeners will be monitored at the EW site to evaluate risk reductions achieved by the sediment cleanup.

5.5 Changes in Particle Size Distribution Between the Green River and the East Waterway for Organic Contaminants

The sensitivity analysis evaluates particle size distribution using three methods; all of which account for the difference in particle size of organic contaminants between suspended solids data in the Green River compared to the fine-grained sediment that enters the EW (Section 4.6).

Each of the three methods to adjust for the effects of particle size for organic chemicals increased concentrations as expected, but the magnitude of the impacts varied across methods (Figure 5-1 and Table 5-1). Excluding samples with less than 60 percent fines only resulted in small increases of the overall PCB and dioxin/furan concentrations (6 percent for total PCBs and 3 percent for dioxins/furans), because the remaining samples still contained a measurable quantity of coarse-grained material(Section 4.6.1). Fines normalizing, where all samples are included but normalized based on fines content, increased concentrations by 28 percent (total PCBs) and 27 percent (dioxins/furans). Finally, the surface area method of fines adjustment (which accounts for variations in particle size distribution within the fines category and for changes in particle size distribution during transport from the Green River to the EW [Section 4.6.3]) resulted in the largest increase (approximately 65 percent) in concentration.

5.6 Green River Flow and Precipitation Conditions

As discussed in Sections 2.1, 4.5.1, and 4.7, COC concentrations in Green River suspended solids vary over time with changing flow and precipitation conditions, which affects the solids introduced into the river, stormwater inputs, dam releases , and erosion of Green River bed material.

Weighting for river flow and precipitation resulted in different outcomes, depending on the contaminant (Figure 5-1 and Table 5-1); total PCB concentrations declined 20 percent, dioxins/furans showed a slight increase, and arsenic concentration increased 28 percent. These changes are due to the large proportion of time that the Green River is in the baseflow condition with low flow and low precipitation. As discussed in Section 4.5.1, arsenic concentrations tend to be higher during baseflow conditions without precipitation and runoff diluting naturally occurring arsenic associated with Green River bed material. PCB concentrations tend to be lower during baseflow when the influence of stormwater runoff is reduced. As discussed in Section 4.7, river flow/precipitation weighting was not used to establish AB concentrations because of uncertainties and assumptions that are part of the calculation process and flow/precipitation binning methodology. In addition, the methodology effectively reduces the sample size to that which remains in each of the four individual river condition bins, further increasing uncertainty in this estimating method.

5.7 Future Urban Inputs

Diffuse inputs from urbanized drainage basins (i.e., inputs related to general urban activity rather than a specific contaminant source) will be an ongoing contributor of chemicals to the EW; therefore, it is important to consider potential influence these sources may have on the sediment concentrations in the EW. The sensitivity analysis includes an evaluation of the effects of EW and LDW lateral inputs on the average concentration in the AB dataset, as described in Appendix A, Part 3, of this document. The chemical concentrations used in this analysis were derived using the current lateral dataset and applying best professional judgment to estimate the concentrations of chemicals in discharges following future source control actions. Including estimated future EW and LDW lateral inputs results in an increase in organics concentrations by 5 percent (total PCBs) and 4 percent (dioxins/furans) compared to the AB dataset without EW and LDW lateral inputs (Figure 5-1). There is no change in average arsenic concentrations.

As discussed in Sections 2.2 and 3.2, the average mass and contaminant levels from lateral inputs to the EW and LDW are likely to change due to the influence of ongoing and future source control measures implemented as part of discharge permits, municipal stormwater permits, upland contaminated site cleanups, and CERCLA activities.

5.8 Arsenic Post-Depositional Processes

Arsenic sediment contaminant concentrations can change following deposition due to biological, chemical, and physical processes, which contribute uncertainty to expectations for future sediment concentrations regardless of incoming AB concentrations. This AB evaluation only assessed sediment concentrations entering the EW and did not assess changes to bedded sediment concentrations of PCBs, dioxins/furans, or arsenic following deposition. The Green River suspended solids arsenic concentrations are higher than observed bedded sediment concentrations within EW and post-remediation cleanup sites proximate to the EW. This difference likely stems from biogeochemical processes that modulate the concentration of arsenic in bedded sediment~~ (Section 4.4), the effect of which could not be calculated and thus included in the AB value for arsenic. Therefore, the arsenic AB value based on suspended solids data may be higher than what ultimately becomes the EW bedded sediment concentration over time~~. Table 5-2 compares the arsenic concentrations in the AB dataset (Green River suspended sediment centrifuge/filter solids samples) with arsenic concentrations in bedded sediment in the EW, and in two completed sediment cleanup sites in West Waterway and LDW (post-remediation conditions evaluated during long-term monitoring).

Concentrations associated with bedded sediment can be influenced by biogeochemical conditions that affect the partitioning behavior and mobility of arsenic, both in the water column and in sediment (Fendorf et al. 2010; Campbell and Nordstrom 2014). Arsenic partitioning from particles to water is enhanced by increasing pH and salinity in the water column. Arsenic can also be mobilized from deposited sediment particles under reducing conditions. These complex biogeochemical processes can result in the release of arsenic into the dissolved phase both from suspended particles in the water column and from deposited sediment. PCBs and dioxins/furans are comparatively inert to these mechanisms. The effects of post-depositional biogeochemical processes are difficult to predict and therefore were not incorporated into the AB estimate for arsenic.

5.9 Future Inputs to the Green River Watershed

The AB evaluation is based on recent data and is considered representative of current conditions in the Green River Watershed. Inputs to the Green River Watershed could change over time. For example, stormwater regulations and improvements could lead to a reduction in the amount of stormwater or improvements in contaminant levels into the Green River Watershed over time. Alternatively, new development within the watershed could result in land use changes that increase stormwater contributions in the watershed.

5.10 Lower Duwamish Waterway Bedded Sediment

As discussed in Section 2.3, a small portion of bedded sediment within the LDW Superfund site resuspends and moves downstream into the EW. This is not considered part of AB and is not accounted for in the AB dataset or sensitivity analyses.

The impact of omitting the contribution of resuspended LDW bedded sediment to AB is small for a couple of reasons. First, current modeling indicates that sediment load to the EW from LDW bed is minimal (0.24 percent of the total load; Figure 2-2). Second, in the long term, LDW bedded sediment concentrations following completion of the CERCLA cleanup are expected to equilibrate with incoming concentrations from the Green River and urban inputs from LDW lateral inputs. Following remediation of LDW, monitoring data will be available to better understand LDW site-wide concentrations.

5.11 Conclusions

The Green River suspended solids dataset was assessed to understand potential uncertainties in the data and to select a final AB dataset. Although uncertainties are inherent to the AB estimating process, the overall conclusion is that data are suitable for representing AB for the EW.

Most of the evaluated uncertainties had a minor impact on average AB concentrations. However, adjusting organics data based on percent fines was considered a meaningful adjustment to accurately reflect the sediment transport CSM between the Green River and the EW (Section 4.6.2). Therefore, fines normalization was selected as the method for particle size adjustment for the final estimate of AB for PCBs and dioxins/furans. Arsenic AB is estimated without particle size adjustment and may be higher than what ultimately becomes the EW bedded sediment concentration over time due to influence of biogeochemical processes.

6 Summary and Conclusions

A collaborative process between EPA, EWG, and key stakeholders was used to evaluate available data to develop an AB estimate for the EW. A logical step-wise approach was followed to understand sediment transport into the EW, screen potentially applicable datasets, evaluate the remaining data, and select a data treatment approach. This section presents the final AB values from the selected AB dataset.

As described in Section 4.8, the following data refinements were made:

- Use centrifuge and filter solid samples only (exclude sediment traps)
- Use PCB congener data only (exclude all Aroclor data)
- Use only detected PCB congeners in summing
- Calculate AB for the four dioxin/furan congeners that are primary contributors to human health seafood consumption risk (while also presenting the dioxin/furan TEQ for informational purposes) and use ROS to account for non-detected results when calculating summary statistics
- Perform fines normalization for organic contaminants to account for particle size differences between Green River samples and suspended solids flowing into the EW
- All centrifuged and filtered solids sample data used without any adjustment for arsenic

Based on the above data refinements, various summary statistics for the AB dataset are presented in Table 6-1.[23] The UCL95 on the mean will be used in future EW decision documents in place of the natural background-based PRG values presented in the EW FS. Mean, median, and two upper tolerance limits (90/90 UTL and 95/95 UTL) are also presented in the table for informational purposes.

The AB values presented in the following bullets are based on the 95 percent upper confidence level on the mean (UCL95) and rounded to two digits:

- Total PCBs 31 µg/kg dw
- Arsenic 20 mg/kg dw
- 1,2,3,7,8-PeCDD 2.1 ng/kg dw
- 2,3,4,7,8-PeCDF 1.1 ng/kg dw
- 2,3,7,8-TCDD 0.71 ng/kg dw
- 2,3,7,8-TCDF 1.2 ng/kg dw

[23] Dioxin/furan TEQ values are presented in Table 6-1 for informational purposes.

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Tables

Figures

Appendix A
Supporting Documentation

Appendix B
Anthropogenic Background Dataset